N95- 14076

MARTIAN ENVIRONMENTAL SIMULATION FOR A DEPLOYABLE LATTICE MAST

Robert M. Warden
AEC-Able Engineering Co. , Inc.

ABSTRACT

The Mars Pathfinder mission (formerly Mars Environmental Survey or MESUR) is scheduled for launch in December 1996 and is designed to place a small lander on the surface of Mars. After impact, the lander unfolds to expose its solar panels and release a miniature rover. Also on board is the Imager for Mars Pathfinder (IMP) binocular camera which is elevated by a deployable mast to obtain a panoramic view of the landing area.

The design of this deployable mast is based on similar designs which have a long and successful flight history. In the past when this type of self-deployable mast has been used, a rate limiter has been incorporated to control the speed of deployment. In this application, to reduce weight and complexity, it was proposed to eliminate the rate limiter so that the mast would deploy without restraint. Preliminary tests showed that this type of deployment was possible especially if the deployed length was relatively short, as in this application. Compounding the problem, however, was the requirement to deploy the mast at an angle of up to 30 degrees from vertical. The deployment process was difficult to completely analyze due to the effects of gravitational and inertial loads on the mast and camera during rapid extension. Testing in a realistic manner was imperative to verify the system performance.

A deployment test was therefore performed to determine the maximum tilt angle at which the mast could reliably extend and support the camera on Mars. The testing of the deployable mast required partial gravity compensation to simulate the smaller force of Martian gravity. During the test, *mass* properties were maintained while *weight* properties were reduced. This paper describes the testing of a deployable mast in a simulated Martian environment as well as the results of the tests.

TEST ARTICLE

The IMP Mast Assembly consists of a deployable triangular lattice structure, a base section, a tip section, a launch restraint/release device, and the Imager Camera payload (Figure 1). The camera is mounted to the tip plate and the base plate is mounted to the spacecraft. The lattice structure, when it is retracted, is surrounded by a thin metal cylinder covered by the tip plate and the base plate. Permanently attached to the middle of the tip plate is a center post which is a small rod that extends down through the center of the stowed mast to the base plate where it is captured by a pyrotechnically actuated pin-puller. The center post and pin-puller are needed to hold the stowed mast assembly together and support the camera throughout launch and landing. When the pin-puller is actuated, the center post is released which allows the mast to deploy. The base plate also encloses a set of three springs which are needed to provide the necessary initial deployment force. The extension of the mast assembly lifts and supports the camera above the Mars lander. Electrical cabling is attached along the length of the mast to connect the camera to the spacecraft.

Deployable Lattice Structure

The lattice structure consists of unidirectional fiberglass/epoxy rods, aluminum fittings, stainless steel diagonal cables and stainless steel fasteners. The structure extends and retracts by twisting about the longitudinal axis. When stowed, it acts like a compressed spring that, when released, pushes out toward the extended position. Once fully deployed, the structure becomes rigid. This type of structure has been used frequently in space but every program requirement is somewhat different. A new 18.3 cm (7.2-in.)-diameter mast was needed for this program which was based on similar designs that range in size from 20.3 cm (8.00 in.) diameter to 76.2 cm (30.0 in.). Preliminary tests using an existing mast showed that it was marginally capable of deploying the camera at a 15-degree tilt angle (from vertical) and was unable to deploy the camera at 30 degrees. The design for the new unit has been scaled from existing designs but uses proportionally stronger structural elements while minimizing the weight of all other components.

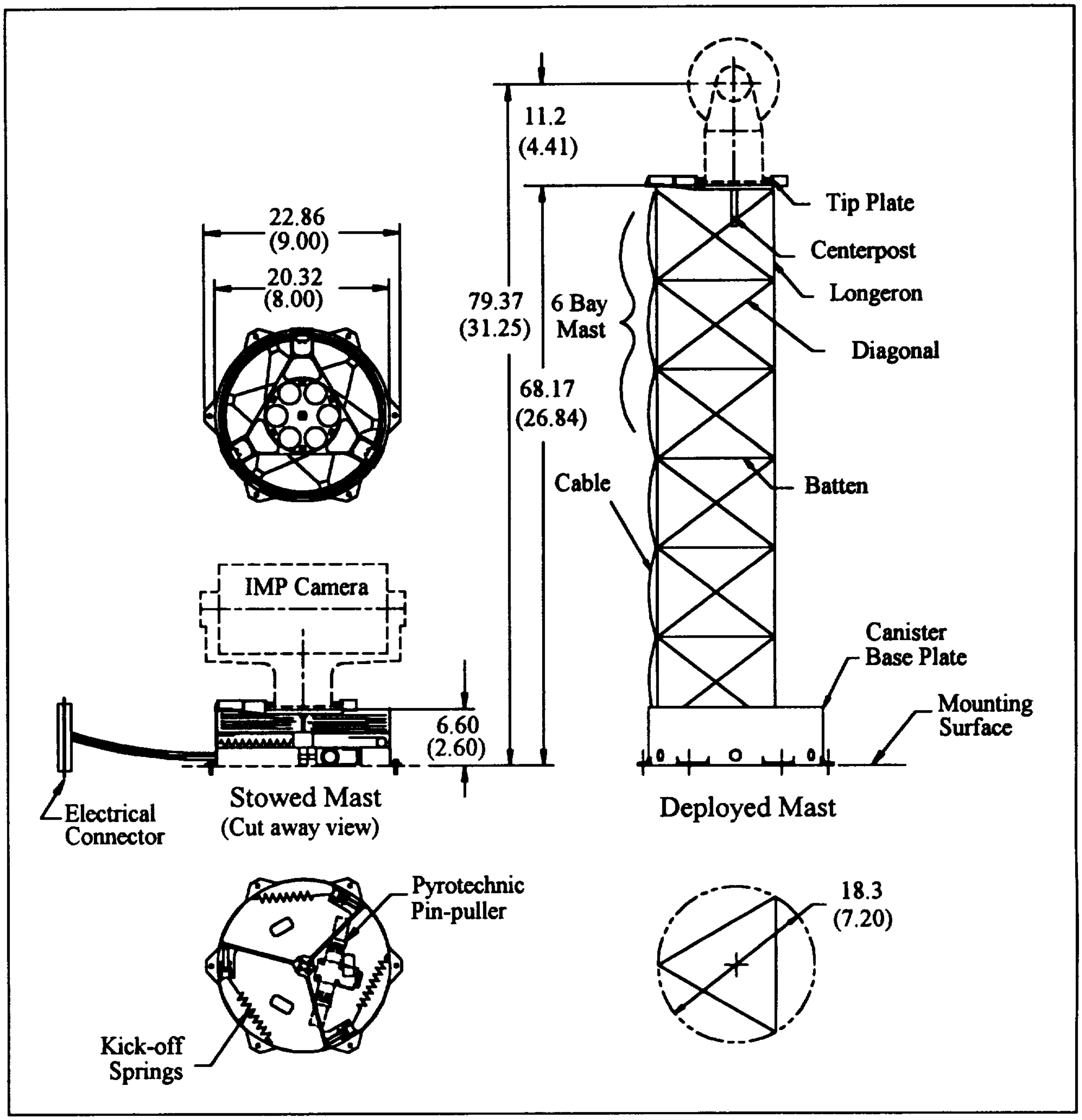

Figure 1: IMP Outline Drawing

Electrical Cables

Attached to the outside of the lattice structure are three electrical cables which are used to electrically connect the camera to the spacecraft. Electrical cables, when attached this way, have previously been shown to have had a negligible effect on the deployment of the mast. For this program, however, the electrical cables are jacketed in a conductive rip-stop nylon jacket. This type of covering promises to be lighter weight but because it is a much looser construction, there was some concern that it may interfere with the deployment of the mast.

Camera Simulator

A camera simulator was needed to simulate the actual flight camera for use in the testing. The mass of the flight camera was specified at 1.4 kg. The mounting configuration and exact moment of inertia had not been determined, so some reasonable assumptions were made to approximate the properties of the camera:

Total Mass: 1.4 kg (3.08 pounds, Earth weight)
Mounting holes: 6X #6-32, 3.00 in. BCD
Moment of Inertia: 0.0044 kg-m^2
Distance from camera mounting surface to CG: 0.0678 m

TEST APPROACH

The main problem in performing the deployment test was how to accurately simulate the deployment conditions on Mars. The force of gravity on Mars is much less than on Earth but the deployment force of the mast and the mass of the components are constant. The 1.4 kg mass of the camera by far dominates the 1.9 kg mass of the total system. To simplify the test, the differences in the weights of all components except for the camera were ignored because they were small compared to the weight of the camera and the push force of the mast. Figure 2 shows the forces involved in the deployment on Mars. Several approaches were considered to try to accurately simulate this condition on Earth.

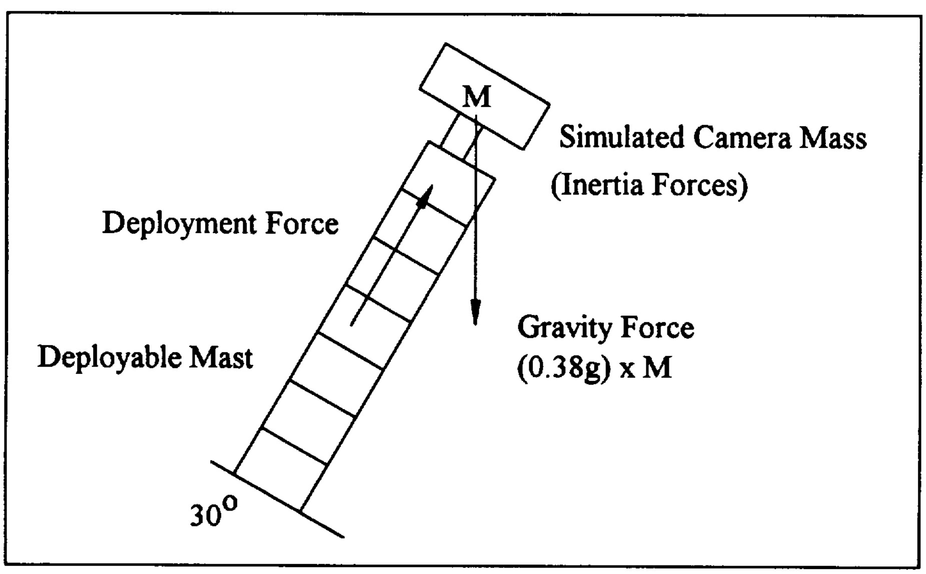

Figure 2: Simple Surface Oriented Force Diagram

Preliminary deployment tests simply used a lighter weight payload to simulate the reduced force of gravity on Mars. The rotational moment of inertia of the flight camera about the axis of deployment was specified by the customer. The simulated payload was configured in such a way as to produce the specified rotational mass moment of inertia and weigh 0.38 times the Earth weight of the camera. The simulated mass ended up looking like a dumbbell with most of the weight on the ends. This method accurately simulated the gravity on Mars and the rotational inertia of the camera but the axial inertia was reduced along with the tip mass.

During deployment of the mast, the tip plate rotates and extends at the same time. When the mast is fully extended, the tip plate over-shoots the end position and continues to rotate due to the rotational inertia of the payload This causes the mast to partially retract as the rotation slows down. At this point, the rotation and extension have momentarily stopped, but the tip plate is still subject to significant lateral motion. The tip plate then reverses direction and the mast deploys again only to over-shoot in the other direction. After a few cycles, the rotational oscillation of the tip plate damps out and after a few more cycles, the lateral vibration damps out.

In order to provide the proper dynamic forces on the mast during deployment, the proper rotational and translational inertia was required as well as the proper gravitational force. Without the correct tip mass, the resulting acceleration and deceleration would be significantly higher which could produce unrealistic loads on the mast. During deployment, the mast is less capable of resisting lateral loads than it is when fully deployed which makes the simulation of the true force balance even more important.

To perform the angled deployment test, an accurate setup was needed which would maintain the rotational and axial inertia of the camera while simulating the proper forces on the mast. The best way to do this is to use the actual camera mass and inertia but simulate the proper g-loading by partially off loading the weight of the camera. Figure 3 shows a more complete description of the forces. A constant-force-suspension system was designed to counterbalance the additional forces imposed by earth gravity. The camera simulator is partially suspended by a long lanyard which is attached to a spring reel device as shown in Figure 4. The spring force acts vertically through a lanyard, opposite the force of gravity. During an inclined mast deployment, the long suspension system closely simulates the force balance on the mast system that will occur on Mars.

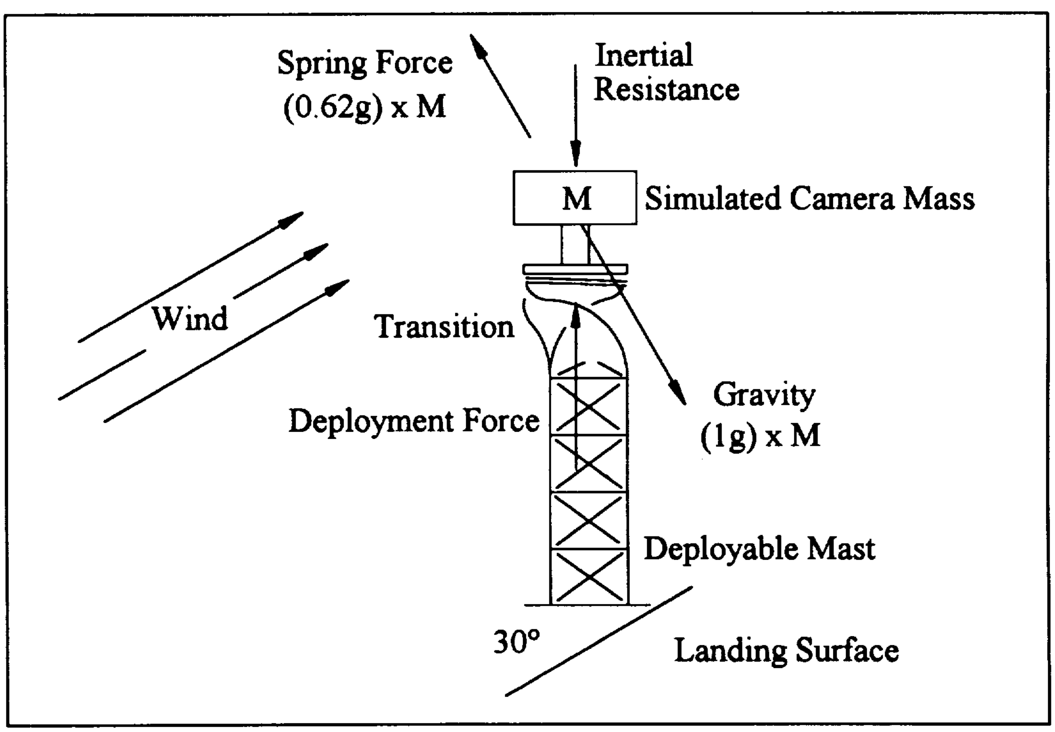

Figure 3: Mast Oriented Force Diagram

The counterbalance spring device was mounted as high as possible to reduce the error caused by the change in angle. Any angle in the counterbalance system is undesirable because it introduces an effective lateral component to the lanyard force. By using a long lanyard, the effect of the lateral displacement during inclined deployment is minimized. The counterbalance was positioned so that the lanyard was vertical when the mast was fully deployed. In this way, the load condition would be most accurate at the end of deployment which is where the dynamic conditions are the most uncertain. In this test, the angle of the lanyard was less than 3.5° from vertical and the error was calculated to be insignificant.

During deployment, the counterbalance system allows the tip of the mast to rotate without resistance whether the spring reel is paying out or reeling in the lanyard. As the tip of the mast deploys, retracts, twists and bends, the counterbalance maintains the correct force orientation on the camera simulator.

It is important to note that the suspension system was designed to be lightweight and very fast acting to allow the lanyard to retract as the mast deployed. In this way, a known vertical force on the mast assembly is maintained throughout the deployment. The lanyard load was set in a static state with analysis indicating only a small decrease in lanyard load during deployment accelerations. The force output of the spring reel was not perfectly constant over the deployment length but the error was disregarded because it was small compared to the push force of the mast and the force of gravity on the camera. The fast response of the spring reel was due to the small weight and size of the components.

TEST DESCRIPTION

An adjustable base structure was constructed with a large flat mounting surface onto which the mast assembly was bolted (Figure 4). The mounting surface was capable of being tilted to simulate an inclined lander position on the surface of Mars. The angle of the mounting surface was adjustable in 5-degree increments. To simulate the lower gravity of Mars, a spring reel device was bolted to the ceiling and then attached to the camera simulator. The mast was first deployed vertically several times. The base was then tilted 5 degrees and the mast was again deployed several times. The tilt angle was increased at 5-degree increments until the mast failed.

Because the mast is triangular, its bending strength varies with its azimuthal orientation. At each tilt angle the mast was mounted in different azimuthal orientations and deployed several times to examine the effect of the mounting condition. The intent of the test was to keep increasing the angle of deployment until the mast broke, then shorten the mast and repeat the test. Preliminary estimates were that the mast could deploy at an angle of only 20 to 30 degrees. Exact predictions were nearly impossible due to the complex nature of the deployment process.

Test Equipment

Base structure with adjustable mounting surface.
Coilable lattice mast.
Camera simulator attached to the top of the mast.
Spring reel attached to the ceiling.
Lanyard to attached the spring reel to the camera simulator.

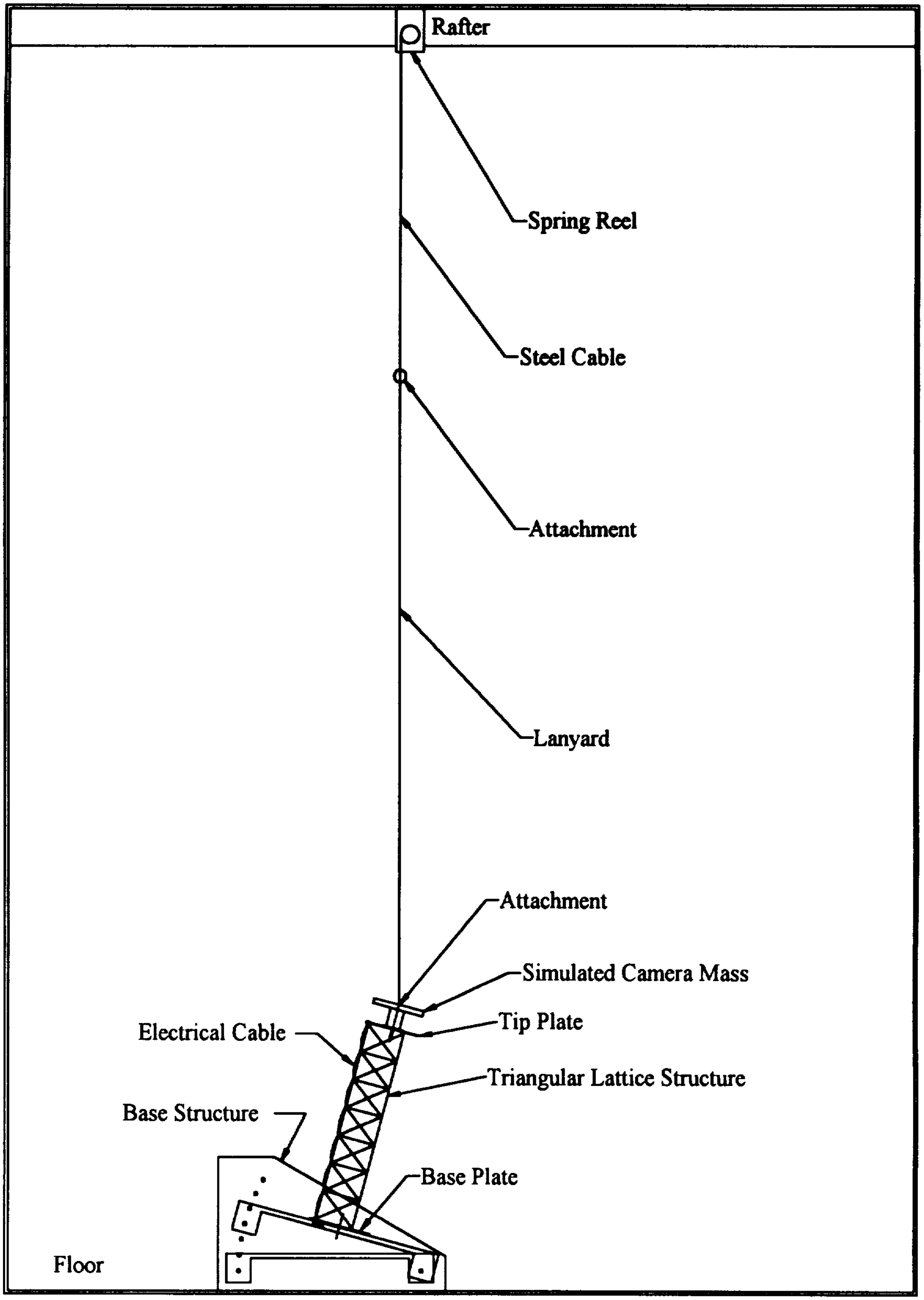

Figure 4: Angled Deployment Test Set-up

TEST RESULTS

Surprisingly, the mast did not fail at the predicted tilt angle of 30 degrees so the tilt angle was increased further at 5-degree increments until the mast finally failed at 55 degrees after being deployed a total of 75 times. The mast was frequently examined for damage. An incipient fracture was finally observed in the fiberglass about three-fourths of the length up the mast after the second deployment at 50 degrees. Another deployment caused the fracture to grow. The angle was then increased to 55 degrees and the mast again deployed successfully but the damage was severe (less than 50% of the fibers were intact). The mast was then carefully retracted and allowed to deploy a final time during which it broke completely. Even in the broken condition, however, the mast successfully deployed and supported the payload, although the strength and stiffness were greatly reduced.

The mast failure was probably not caused by the increased deployment angle. The break may have been exacerbated by excessive handling of the mast (considerable torque was necessary to retract the mast) but it is more likely that the failure was due to fatigue. From these tests, it appears that the mast is life-limited when subject to uncontrolled deployments and after approximately 70 cycles, the fiberglass in the mast began to degrade.

The deployment of the mast was quite rapid and at first appeared to be uncontrolled. The deployment was, in fact, well controlled and very repeatable. The deployment rate of the mast was consistent in these tests and only minimally affected by the angle of deployment. The rapid deployment does cause a significant impact load onto the mounting surface which may be important in the design of the spacecraft.

The camera mass and moment of inertia are probably factors in the cycle life. It is unclear, however, whether an increased mass would improve or degrade the system performance. An increased moment of inertia would slow down the deployment acceleration and deceleration which may be a factor in the mast fatigue. The deployment of the base of the mast is critical to the successful extension of the system. Establishing good base strength early in the deployment sequence ensures good payload support, almost independent of deployment angle or tip mass. The electrical cables appeared to have no effect on the deployment.

CONCLUSION

The deployment test shows that a simple functional test can be performed with successful results in lieu of an extremely complicated analysis. Many simplifications were incorporated into this test in order to make the test less complicated and to reduce the cost. The force of Martian gravity was simulated by partially off-loading the weight of the camera mass simulator. In this way, the actual camera mass and moment of inertia were also simulated.